FIELD OF THE INVENTION

The present invention relates to a beamforming communication
system applying an adaptive method for determining transmit
weights for the various antenna beams.

BACKGROUND OF THE INVENTION

Multiple antenna elements can be used to adapt the effective
radiation pattern to varying channel and interference
conditions. In its simplest form the signal is transmitted
from all the antennas with antenna specific complex weights,
i.e. a weight that is determined by an amplitude value and a
phase. By this means it is possible to achieve a directivity
gain when focussing the transmitted energy to the intended
receivers instead or merely spreading energy uniformly over
the whole coverage area.

There are several techniques commonly used in second and
third generation systems: Conventional beamforming assumes a
reasonably well-behaved propagation and requires a
calibrated antenna array so that a direction of arrival can
be determined from the average correlations of the received
signals. Based on the direction and knowledge of the array
geometry, transmit weights are determined as functions of
the direction. In fixed multibeam antenna systems a set of
fixed beams with different pointing directions is used and
subset of the beams are selected for downlink transmission.
Typically, the beam in which the most power is received is
used for transmission. This technique has less requirements
on calibration compared to conventional beamforming but
still requires a reasonably well-behaved propagation
environment. Yet another technique is closed loop transmit

diversity where the transmitter transmits antenna specific pilots from which the receivers can estimate the channels. The transmitters and the receivers use an agreed set of weights. The receiver determines the weight in the set that

5   best matches the channel and signals this to the transmitter. The weights are in essence adapted to the instantaneous downlink channel.

Another possibility is to transmit antenna specific training signals from which the terminals can estimate the complex

10   valued downlink channel responses. The estimated downlink channels are then fed back to the receiver and used to construct transmit weights, see e.g. Gerlach, Paulraj: "Adaptive Transmitting Antenna Arrays with Feedback", IEEE Signal Processing Letters, Vol 1, No 10, p 150-152, October

15   1994. Such an approach considers only the channel, and a practical implementation will require some form of quantization and agreed code book in order to fed back complex valued channel responses.

A simpler approach is considered in Banister, Zeidler: "A

20   Simple Gradient Sign Algorithm for Transmit Antenna Weight Adaptation with Feedback", IEEE Transactions on Signal Processing, volume 51, No. 5, p 1156-1171, May 2003. Here, a single weight vector for a single user is tracked. This is done by creating two weight vectors as slightly randomly

25   perturbed versions of the currently tracked weight vector. Multiplexed pilot signals are then transmitted so that the receiver can measure the received power on the two weight vectors and report back to the transmitter which pilot was received with the highest power. The transmitter will then

30   replace the currently used weight vector with the weight vector corresponding to the strongest received pilot signal. The process is then repeated in a continuous fashion. Thus, only a single user is considered and only a single bit is fed back to the transmitter for each measurement period. A

35   similar method is proposed in Banister, Zeidler, "Feedback

Assisted Transmission Subspace Tracking for MIMO Systems",
IEEE Journal on Selected Areas in Communications, Vol. 21,
No. 3, p 452-463, April 2003. In this case antenna specific
pilots are used in addition to the pilots used to transmit
5   data, and only a single feedback is generated.

SUMMARY OF THE INVENTION

It is an object of the present invention to achieve a
communication system applying beamforming data transmission
10 that provides improved downlink communication channels
between an access point and several mobile terminals. The
transmission beams are determined by means of weights that
are assigned to the various data streams that are
transmitted over the access point antennas. Data streams can
15 either be dedicated and intended to a single user or common,
intended to multiple users.

It is the principal idea of the present invention to apply a
set of complex transmission weights that is adaptable in
response to appropriate feedback information on transmission
20 quality from receiving units. The set of transmission
weights is shared by the users served by the access point.

Briefly, the method according to the present invention is
performed in an access point sending weighted sets of pilot
signals to a plurality of mobile terminals. The mobile
25 terminals perform measurements on a channel quality
property, which mobile terminal and access point have agreed
upon, and from which a quality indicator of the received
pilots can be derived. The mobile terminals retransmit a
feedback report including said quality indicators to the
30 access point. The access point adapts the set of transmit
weights for the pilot signals in response to the received
feedback reports in order to achieve a maximisation of a
function of said quality indicator and thus optimise the

transmission of the pilot signal. The set of weights could simultaneously comprise beams for transmission to several users as well as to individual users.

5   The present invention allows an adaptation of downlink communication channels with only a limited involvement of the mobile terminals.

It is another advantage of the present invention that an optimisation of downlink channels can be achieved with regard to all potential influences on the communication
10   channel and, particularly, without need for a calibration of access point and antenna.

It is still another advantage of the present invention that the channel adaptation needs not to be based on propagation assumptions.

15   Yet another advantage of the present invention is that the pilots used for measurements for adapting the set of transmission weights are shared by all served users. Further, since the set of weights adapted based on feedback from several users, transmit weights to be used for
20   transmission of the same data to several users can be found.

Other objects, advantages and novel features of the invention will become apparent from the following detailed description of the invention when considered in conjunction with the accompanying drawings and claims.

25   For a better understanding, reference is made to the following drawings and preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a part of a communication system within which the present invention is applied.

Figure 2 shows a signalling diagram illustrating the method according to the present invention.

5   Figures 3a and 3b show short and long measurement periods for pilot signals in a time-frequency space.

Figures 4a and 4b illustrate the change of distribution of antenna beams by means of adapting the vectors of transmission weights for the various pilot signals
10   transmitted by the access point.

DETAILED DESCRIPTION

Figure 1 shows a simplified picture of a part of a communication system 10 within which the present invention
15   can be applied. The radio base station is represented as an access point 11 comprising several antennas $A_1, ..., A_M$ for data transmission to a plurality of mobile terminals MS1,...,MS4, each of which equipped with one or more antennas. The area, which can be served by said access point 11, is referred to
20   as a cell. For the sake of simplicity, the case in which the same transmit weights are applied to all symbols in a pilot sequence is considered. In a multi-carrier system such as OFDM, different parts of a pilot sequence can be transmitted on different carrier frequencies with different transmit
25   weights at the different frequencies. In this context, the weight vector comprises all the weight vectors use at the different frequencies.

The access point comprises M antennas $A_1, ..., A_M$ for transmission of N pilots, which are transmitted with a
30   number of time-, frequency resources, e.g. as shown in figures 3a and 3b. Each pilot sequence p_n (n=1...N) is assigned to a set of complex transmission weights

$w_n = \{w_{n1},...,w_{nM}\}$, whereby each of the weights of such a vector describes the transmission behaviour over the antenna A_m and can be described with a non-frequency selective channel with impulse response $w_{nm}(t) = \xi_{nm} e^{j\varphi_{nm}} \cdot \delta(t - \tau_{nm})$ comprising at least parameters denoting the amplitude ξ_{nm} and phase shift φ_{nm} of the antenna transmission, and optionally a parameter τ_{nm} indicating a certain time delay value for transmitting data over the antenna A_m. The set of M complex transmission weights determines, together with the antenna arrangement and hardware, the direction and shape of the antenna beam. As a particular example, ξ_{nm} may assume a unit value, while the phase is given by $e^{j\varphi_{nm}}$. The aggregate set of phase values from multiple weights operating over multiple antennas, impacts radiation pattern, and for a so-called uniform linear array if $\varphi_i = k \cdot \varphi_0$, where k is an integer, the radiation pattern generally has a direction of a beam in relation to a predefined reference axis. Finally, $\delta(t - \tau_i)$ expresses a time delay τ_i for the transmission of pilot signals relative to a certain fixed point in time. A transmitted pilot signal can thus be regarded to be a known sequence of symbols, which is transmitted with a specific associated weight vector defining a unique beam for each of the transmitted pilot signals, and which can be multiplexed with other transmitted data. In a preferred embodiment, orthogonal pilot sequences are chosen so that the terminals can measure the quality easily.

In the general case in a multicarrier setting using for example OFDM, the nth pilot is a sequence of K symbols $p_n(k)$, k=1,..,K. Each symbol is then transmitted at a certain time and at a certain carrier, and associated with each symbol is a specific weight $w_n(k) = \{w_{n1}(k),...,w_{nM}(k)\}$. For example, different weights are used at different frequencies. In the

following, as mentioned above in order to ease the notation, it is assumed that the same weights are used for all pilot symbols. The mobile terminals $MS_1, ..., MS_i$ receive fractions of the transmitted pilot beams, depending on their position

5   with regard to transmission angel, distance to the access point and radio propagation conditions and perform measurements of certain properties of the downlink channel on which the pilot signals have been received. From said measurements the mobile terminals determine a quality

10 indicator of the received pilot signals that is transmitted back to the mobile terminal as feedback information on the experienced reception quality of each of the pilot signals from each of the mobile terminals.

Figure 2 illustrates a signalling diagram for the method

15 according to the present invention. The access point transmits 201 a set of pilot sequences $p = \{p_1, ..., p_N\}$ whereby each of the pilots p_i is assigned to a set of complex weights $w_i = \{w_{i1}, ..., w_{iM}\}$. The illustrated example assumes an access point with two antennas, i.e. M=2, and four pilot

20 signals, i.e. N=4. There are several possibilities to define an initial set w of weight vectors for the pilots. It is one conceivable alternative to define an initial set of weight vectors that spreads the pilot beams equally over the entire cell area that is served by the access point. This can be

25 achieved, e.g., by the set of weight vectors defined below:

$$\mathbf{w}_1 = \begin{pmatrix} 1 \\ e^{j\pi/4} \end{pmatrix}, \mathbf{w}_2 = \begin{pmatrix} 1 \\ e^{j3\pi/4} \end{pmatrix}, \mathbf{w}_3 = \begin{pmatrix} 1 \\ e^{-j\pi/4} \end{pmatrix}, \mathbf{w}_4 = \begin{pmatrix} 1 \\ e^{-j3\pi/4} \end{pmatrix}$$

In this set, the first antenna transmits always with a weight 1 while the second antenna transmits with a certain phase shifting $e^{j\varphi}$, which in this example causes four pilot

30 signals each of which spaced out with $\pi/2$ distance between

each other. However, it is notwithstanding possible to
define other types of spacings of the pilot signals, e.g. if
there is already information available about the position of
mobile terminals in the cell so that the weight vectors can
5   be selected in such a way that the pilot beams already focus
on a specific area. The access point also instructs the
mobile terminals to use a certain measurement period during
which the mobile stations measure the received quality of
the pilot signals. This will be explained later in
10   connection with figures 3a and 3b.

A mobile terminal within the cell that is covered by the
access point will thus receive one or several of the
transmitted pilot signals depending on its position in
relation to the transmitted pilot beams. It is one basic
15   idea of the present invention that the access point can
improve the downlink channel quality by help of feedback
information from the mobile terminals in response to the
received pilot signals and that said feedback information is
applied to adapt the set of weight vectors of the pilot
20   signals. For this purpose mobile terminals perform channel
measurements 202 to derive a quality indicator for each or a
subset of the pilot signals. Said quality indicator is
considered to be a value from which the access point can
conclude the downlink transmission quality for the various
25   beams to a specific mobile terminal.

There are numerous alternatives of measurements of channel
properties that can be applied as a metric to derive said
quality indicator. Examples of such measurements can relate
to a ratio, e.g. the signal-to-noise ratio (SNR) or the
30   signal-to-interference ratio (SNIR), or a power level, e.g.
the received signal power level or the received interference
power level. In addition, instantaneous or average
interference plus noise levels may be exploited in

combination of above quality indicator metrics. Another alternative of a metric is an effective SNR- or SNIR-value, which can be used, either at the mobile terminal or the access point, to deduce a modulation and coding scheme (and
5   hence maximizing the bit rate). The access point instructs 206, at appropriate instances in time, the mobile terminals about the specific channel property or the properties that the mobile terminal shall use to derive the quality indicator and instructs about a certain measurement period
10 during which the indicated channel property shall be measured. The access point schedules measurements and pilot transmissions depending on the expected rate of change of the radio channel, required accuracy, and amount of data to be transmitted and measurement capability of the terminals.
15 The measured channel property itself can be regarded as an adaptive quantity, which can be changed with regard to changes, e.g., of the propagation conditions between access point and mobile terminals.

Figures 3a and 3b show two examples of measurement periods
20 during which the mobile stations measure the received quality of the pilot signals. The illustrated pilot signals are transmitted with a number of time- and frequency resources. Figure 3a relates to a scenario with two antennas with uncorrelated fading and a set of four initial transmit
25 weights as defined above. In order to track variations of the instantaneous channels and to be able to adapt said channels the terminals use short measurement periods T_1 to achieve frequent updates of the transmit weights. Figure 3b relates to a beamforming scenario assuming two antennas
30 separated half a wavelength and having correlated fading. A set of beamforming weight vectors is defined as above in order to achieve a set of beams pointing in different directions. In this case it is expected that the best beam varies relatively slowly and therefore a longer measurement
35 period T_2, as illustrated in figure 3b, can be applied.

The following assumes, as an example, that the received downlink power is the channel property on which the determination of the quality indicator of the pilot patterns is based. The mobile terminal will measure 202 said power value for each of the received beams and determine the best pilot or, alternatively, determine a set of best pilots, e.g. those pilots having a measured channel property value that is above a certain threshold value. The mobile terminal then determines the quality indicator for each pilot signal as a function of the measured channel property. The derived information is sent back to the access point as feedback information 203, preferably in form of a quality report of the downlink channel properties of each mobile terminal comprising information on a number $n \leq N$ of the pilot signals including said quality indicator and at least an identification of the pilot. Optionally, the report can also include an indication of the channel property on which said quality indicator is based and a time indicator when this measurement was done. The method according to the present invention implies thus the advantage that the necessary feedback information can be considerably reduced.

The access point receives thus an indicator of the downlink reception quality of the mobile terminals within its coverage area. In a next step the access point can adapt 204 the pilot beams for the mobile terminals in order to increase the downlink channel quality for the beams that are represented by the pilot signals. By adapting the pilot signals, and correspondingly the measurement periods, the feedback information, which is returned from the mobile terminals, can be optimised, e.g., with regard to different terminal speeds or different coherency bandwidths. High speed mobile terminals need to update the transmission weights more often and need a shorter measurement period. In this case it is advantageous to use a smaller set of

transmission weights. However, a mobile terminal with low
mobility can use a larger set of transmission weights and
longer measurement periods. One example of an adaptation
mechanism for the pilot weight vectors could be described as

5   follows: On reception of a feedback report for previously
transmitted pilot signals including a quality indicator for
each of said signals the weights of the pilot signal having
the smallest quality indicator is adapted in such a way that
the beam representing said pattern is located between the

10   two pilot patterns having the largest quality indicators.
Another way to create new weight vectors is to generate new
weight vectors by means of random perturbations of the best
weight vectors, i.e. comprising the largest quality
indicators. However, instead of performing an adaptation it

15   can already be sufficient to select the beam having the
largest quality indicator for a specific mobile terminal.
Thus, at the next instance the pilot signals are transmitted
205 with the improved set of weight vectors.

Figures 4a and 4b show an example of adapting the set of

20   transmission weight by using the method according to the
present invention. Initially, as shown in figure 4a, the
access point 41 selects a large set of random transmission
weights for generating a widely separated group of beams 42.
The access point 41 then adapts said transmission weights

25   successively in response to the received quality reports
that the mobile terminals 43 retransmit as feedback
information of the transmitted pilot signals. Figure 4b
illustrates that the access point 41 learns in which way the
mobile terminals 43 are grouped and, thus, which of said

30   transmission weights, corresponding to only a small number
of beams, must be probed. In a conceivable embodiment of the
method according to the present invention the access point
41 can during operation scan the entire coverage area with
certain time intervals in order to update the set of

transmission weights while "hot areas" containing a larger number of mobile terminals 43 are updated more frequently.

In general, past and current measurement reports from the terminals are used, and the adaptation can be viewed as a
5   mapping from the set of current and previous weight vectors in addition of to the quality reports to a set of new weight vectors in addition to conditions such as the whether each beam should serve one or several users. This can be formulated in the general case as a two step procedure.
10   First an objective function f is defined as :

$$f(W, Q, w).$$

W is the set of the previous and current weights, Q is the set of quality indicators corresponding to the weight vectors within W, and w is a set of weights contained in W.
15   The scalar valued cost function will thus associate an accumulated quality measure for the weights w. In this way, a set of best weights can be found as

$$w_{best} = \arg\max_w \left(f(W, Q, w) \right)$$

The cost function can e.g. calculate a condensed quality
20   measure for each weight, and group the weights in subsets, possibly based on a distance measure such as an inner product or an Euclidian distance. The objective function can then be e.g. the sum of quality measures when one vector is taken from each subset. Based on the set of best weights, a
25   new set of weights can be obtained as

$$w_{new} = g(w_{best})$$

Note that the number of weights in w_{new} can be larger than the number of weights in w_{best}. The function $g(\cdot)$ can form a new set of weights such as linear combinations of the input weights, random perturbations, and/or deterministic time-varying functions.

Note that the present invention is used in a multi-user scenario. The access point receives multiple feedback reports from a plurality of mobile terminals, which all have received a transmitted set of pilot patterns. The feedback reports, i.e. the quality indicators with respect to the various pilot patterns, depends, however, on the position of the mobile terminal within the coverage area of the access point. This scenario implies thus an adaptation of the set of transmit weights for the pilot patterns that intends to optimise the downlink channel quality with respect to all mobile terminals.

In the following, this is elaborated in more detail. Suppose that several users are to be served with a single beam. A set of beams is then generated, and for each weight, quality reports are obtained. A quality measure for each beam can then be taken as the lowest reported quality report for all the terminals served. A single best beam can then be taken as the beam with the highest beam quality measure and a new set of weights can be generated as random perturbations of this best beam.

Suppose that several users are served and that individual beams are used for all the users. A set of weight pairs can then be generated and an aggregate quality measure can then be obtained for all weights using the quality reports from all the terminals. In each pair of weights, the best weight can be identified and a new set of weights can by e.g.

perturbing each best weight. This procedure is then repeated.